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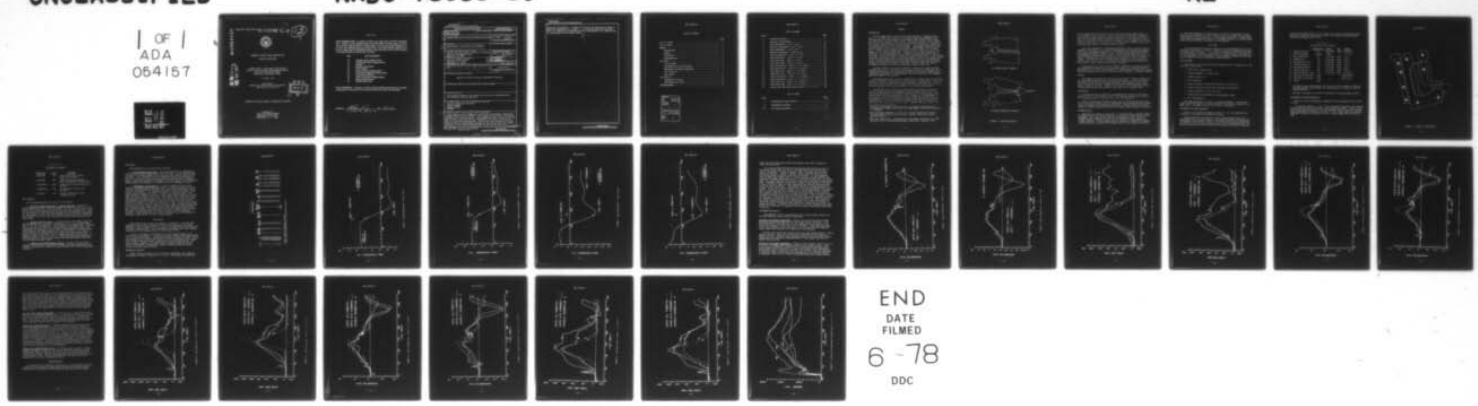

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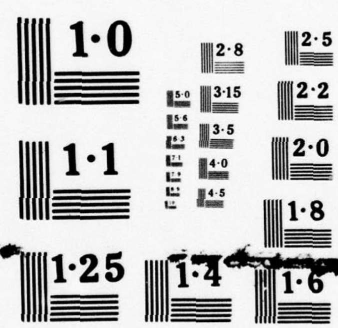


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REPORT NO. NADC-78055-60 

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# POWERED INERTIA REEL RETRACTION DURING EJECTION



Kenneth Miller, Alan Cantor, William Ward
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

20 APRIL 1978

Final Report
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Work Unit No. A5312C-54-2



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Prepared for
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The purpose of this program was to determine the potential effectiveness of upper torso restraint afforded by PIR (Powered Inertia Reel) actuation at inception of the ejection stroke. This program was jointly funded by the Navy and Air Force, and the results are applicable to the Navy A-7 and the Air Force A-10 aircraft escape systems. Twelve tests were conducted on the NADC Ejection Tower to compare dummy responses for six sets of tests with initial conditions of PIR retraction being varied in each set (one test with over

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retraction, one without). A number of the tests were duplicated in order to demonstrate repeatability of results. It was demonstrated that the tested PIR is not effective in overcoming ejection loads imposed on the dummy during the onset phase of the catapult stroke.

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# SUMMARY

## INTRODUCTION

The most common spinal injury caused during ejection is compressive fracture. It is usually the consequence of poor positioning and alignment of the vertebrae under +Gz loads imposed by the catapult power stroke of the ejection seat which causes vertical column flexion. The anterior portion of the vertebral body of one of the vertebrae tends to collapse and in the process is crushed by the vertebral body of the next vertebrae above[1]. The catapult power stroke phase of ejection takes from 170 to 200 milliseconds. Approximately one-half of this time is devoted to the buildup of acceleration (rate of onset) to its maximum level. This is usually accomplished during the first 4 inches (10.1 cm) of seat movement up the aircraft guide rails. During this time, spinal compression is occurring. As the acceleration force is applied along the longitudinal axis of the spine, the vertebral segments compress the intervertebral discs. Under ejection conditions, where the crewman is positioned properly, the disc will prevent contact of the vertebral segments, and anterior wedge fractures will not be experienced. Figure 1a shows proper vertebral positioning which should occur when the ejectee is properly aligned with the back of the seat. Figure 1b shows how improper vertebral positioning can result in compression fracture under load.

Shoulder restraint is required to maintain the spine in a proper position during ejection, but in most cases passive upper torso harness restraints are not tightened sufficiently to give optimum positioning for ejection, therefore PIR retraction was developed to take up harness slack and preposition the crewmember's upper torso against the seat back.

When powered retraction is used to "preposition" the upper torso prior to the onset of acceleration encountered in ejection, there is every reason to expect that vertebral injury as a result of spinal misalignment will be minimized. It will also improve seat stability during catapult and rocket thrusting since there will be less excursion of the center of gravity (c.g.) for the seat-man mass.

Although the PIR has found wide acceptance in most ejection seat systems, there is no data available to determine its effectiveness when its action is initiated simultaneously with catapult initiation of the ejection seat. Most present day Navy escape systems utilize PIR's designed to the requirements of MIL-D-81514[2]. With a great majority of these systems, the catapult firing is delayed (usually 0.3 sec.) to allow for adequate canopy removal time and torso prepositioning. The PIR was therefore designed to utilized this time and its performance was based on the 0.3 sec. delay[3]. However some jet aircraft have

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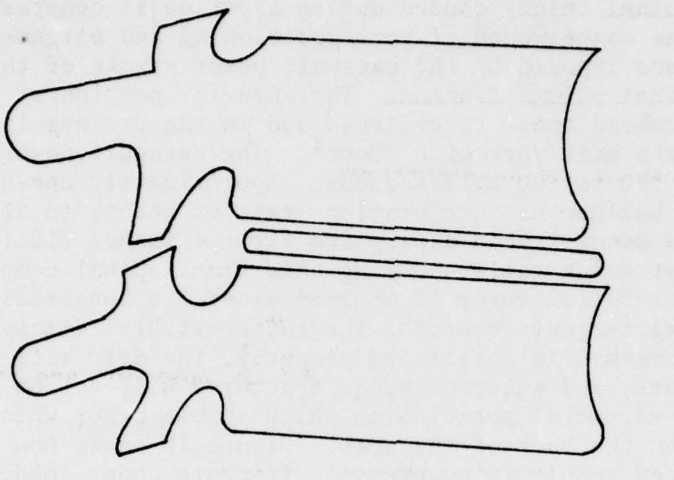
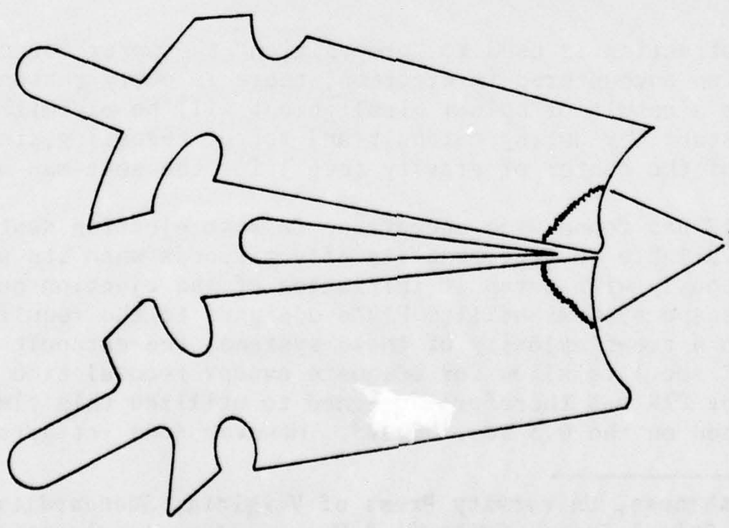
[1] Aircraft Crashworthiness, University Press of Virginia; Standardization & Interpretation of Spinal Injury Criteria & Human Impact Acceleration Tolerance, L.E. Kazarian.

[2] MIL-D-81514B(AS) Amendment 5, 25 May 1972 - Military Specification Device, Restraint Harness Take-Up Inertia-Locking, Powered - Retracting: General Specification for.

[3] Report No. NADC-AC-6810 - Determination of Performance Parameters for a Power Haul Back Inertia Locking Shoulder Harness Take Up Reel, Schulman, 1968.



(a) Proper Spinal Alignment




(b) Spinal Compression Fracture

FIGURE 1 - Vertebrae Positions

escape systems which do not work in conjunction with a canopy removal delay. If the crewmember is out-of-position, there is the potential for spinal alignment injury or body contact with the airframe structure if the PIR cannot function and haul back the occupant before seat motion up the rails. This situation is more prevalent in multiplace aircraft where a crewmember can be "command ejected" while leaning forward, and it is also applicable in single place aircraft in cases where the pilot cannot preposition himself before ejecting.

Tests were conducted on the NAVAIRDEVCEN ejection tower to evaluate the performance of a PIR when it is initiated simultaneously with ejection seat catapult initiation to determine whether the PIR is effective in positioning/restraining the crewmember during the catapult stroke. Twelve ejection tower tests were conducted under a planned ejection load of 12-14 G's and an onset of 180-200 G/sec which is characteristic of the catapult phase of both the A-7 and A-10 escape systems. Six PIR's were fired to compare dummy response with six ejections in which the reel was not fired. The parameters of body position and inertial reel lock as well as power retraction were used as variables.

Data analysis for these tests was limited to phenomena occurring during catapult stroke only since motions occurring after catapult tube separation are not significant to this study, and they may not be representative of what occurs during an actual ejection which includes rocket thrusting in addition to catapult stroking.

## RESULTS

Data analysis revealed that there was no significant difference between tests with and without powered retraction during catapult onset. A minor improvement was noted when the reel was fired ballistically. Some harness slack was taken out of the restraint system, consequently the dummy was prevented from leaning further forward in the seat. However, there was very little improvement from its initial position before and during the onset phase of the catapult stroke.

## CONCLUSIONS

1. The tested PIR was not effective in overcoming loads imposed on the dummy during the onset of the catapult stroke of the ejection and did not position the test mannequin properly in the seat until after tube separation.

2. Slack in the restraint system was taken up by the fired PIR during the catapult stroke of the ejection seat and consequently limited additional dummy forward motion as compared to an unpowered inertia reel. The slack take-up of the PIR resulted in lower shoulder strap loads on the dummy during this phase of ejection.

## RECOMMENDATIONS

1. Based upon the results of these tests it is apparent that a time delay should be provided for in the ejection sequence to allow for PIR prepositioning of the crewmember. This required time delay may be significantly less than the 0.3 seconds presently being used in many ejection systems for canopy removal and crewman retraction. A test program should be conducted to determine the minimum time delay needed to preposition the crewman prior to seat catapult initiation.

2. These tests addressed the effectiveness of the PIR in retracting the torso while under acceleration. Further, kinesiology should be conducted to determine injury potential to the spine while in motion under acceleration. Studies should also be made to determine the effect of the changing seat/man c.g. during initial rocket burn and after full retraction has been obtained.

## TEST SETUP

All tests described herein were conducted at the NAVAIRDEVCEN Ejection Site. The ejection seat tower is a 150-ft. structure inclined and supported at an angle of 20 deg. from the vertical. It is capable of accepting any ejection seat and has been used for a variety of studies related to egress systems. Being man-rated it is an important tool in determining the physiological acceptability of escape system acceleration forces using human volunteer subjects.

### TEST EQUIPMENT

The following list contains the major components used in conducting the tests described in this report:

1. NADC 150-ft. ejection tower
2. Modified ESCAPAC 1A-1 ejection seat
3. RSSK-8A survival kit
4. NB-11 Parachute
5. Pacific Scientific Powered Inertia Reels, P/N 0113347-03
6. Pacific Scientific Inertia Reel Cartridges, P/N 0113226-11
7. Ignition Element, Electric, MK17 Mod 0
8. 95 Percentile Alderson Model CG Anthropomorphic dummy
9. MA-2 Torso Harness

The dummy weighed 91.6 KG (202 lb.) including equipment. Its head neck complex was bolted rigidly to prevent movement of the head with respect to the upper torso. The upper torso was free to pivot at the pelvis.

### INSTRUMENTATION DATA/TECHNIQUES

Table I lists the data recorded for each test. All instrumentation was calibrated in accordance with standard procedures.

Analog signals were recorded on a direct writing Honeywell Model 1912 oscillograph for "quick-look" analysis, and parallel recorded on an Ampex model 1300 magnetic tape recorder to permit a more detailed data analysis subsequent to the test, as well as being a backup in case of an oscillograph failure. The analysis procedure consisted of digitizing the analog curves (100 Hz filtered)

from the oscillograph record or tape playback with a Hewlett Packard Model 9825A calculator system, and replotting the results in a format which could be more easily used to compare sets of data.

TABLE I

Instrumentation Data Channels

| | | Manufacturer | Model | S/N | Range |
|---|---|---|---|---|---|
| 1. | Catapult Pressure | CEC | 4-326-0008 | 6896 | 0-2500 psi |
| 2. | Seat Displacement | Grumman | SPOOL | -- | 1 = 6 in. |
| 3. | Seat acceleration | CEC | 4-202-0001 | 15955 | ±25 G |
| 4. | Catapult acc. | CEC | 4-202-0001 | 11318 | ±25 G |
| 5* | Horizontal Chest Acc. | CEC | 4-202-0001 | 19232 | ±50 G |
| 6* | Vertical Chest Acc. | CEC | 4-202-0001 | 14318 | ±25 G |
| 7* | Horizontal Head Acc. | CEC | 4-202-0001 | 20644 | ±100 G |
| 8* | Vertical Head Acc. | CEC | 4-202-0001 | 10032 | ±100 G |
| 9. | Inertia Reel Cart. Pres. | CEC | 4-326-0008 | 13687 | 10,000 psi |
| 10. | Right Roller Yoke force | NADC | -- | -- | Calibrated |
| 11. | Left Roller Yoke force | NADC | -- | -- | to 500 lb. |
| 12. | Strobe | NADC | -- | -- | ** |

* The head and chest accelerometers were mounted within the dummy and reference the dummy vertical and horizontal axis and should not be related to seat and ground references.

** Provides a 3-ms pulse to correlate instrumentation and photographic records.

## PHOTOGRAPHIC EQUIPMENT/TECHNIQUES

Table II lists the photographic equipment and their placement for the series of tests.

Coverage from cameras 1, 2, and 3, which contained timing marks, were analyzed using the Hewlett Packard Calculator system mentioned previously. Figure 2 shows the locations of photo targets on the seat and dummy that were used for obtaining dummy displacement in relation to the seat vs. time. These targets were measured, digitized, and stored in the 9825A in order to analyze dummy motion relative to time.

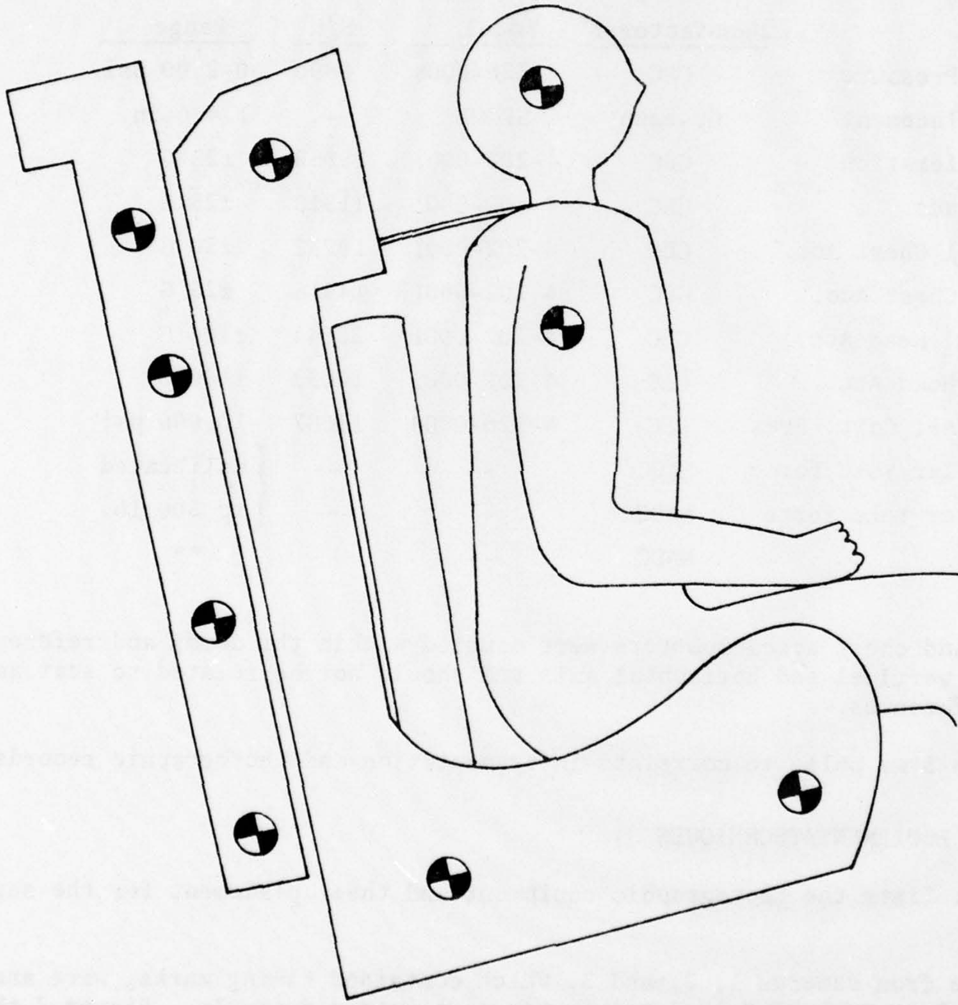


FIGURE 2 - Location of Phototargets

TABLE II

Photographic Equipment

| Camera Type | F.P.S. | Coverage |
|---|---|---|
| 1. Milliken | 400 | Right side of seat covering first 8 ft of travel |
| 2. Milliken | 400 | Right side of seat covering the 6th through 13th ft of travel |
| 3. Photosonics | 1000 | Right side of seat covering 0-10 ft up rails |
| 4. Photosonics | 1000 | Covering top of seat 0-10 ft up rails |
| 5. Milliken | 400 | 45 deg. right front of seat tracking up rails |

## TEST VARIABLES

The following parameters were varied for the program:

1. Ballistic Powered Retraction vs. Inertial Restraint - Three PIR's were obtained from Pacific Scientific Corporation for use in these tests. Each inertia reel was used for at least two tests. The first of these tests did not utilize ballistically powered retraction, while the succeeding test did. After the three PIR's were fired, they were shipped to Pacific Scientific Corporation for refurbishment. These three PIR's were again used on the seat to obtain the second series of six tests, three using ballistically powered retraction, and three without.

2. Initial Ejection Position - Initial positions of the dummy in the seat were established at 2.5 cm (1 in.) displacement, 7.6 cm (3 in.) displacement and 12.7 cm (5 in.) displacement. The displacement was measured from a reference point on the seat head rest to the targeted point on the dummy's head. Zero displacement was established with the dummy sitting against the parachute pack without support and without tension on his restraint system. A 12.7 cm (5 in.) displacement was the maximum distance the dummy could lean forward without having to resort to an artifact such as a wedge to maintain that position. The dummy was limited to the 12.7 cm (5 in.) displacement because the rubberized coverings around its lower torso and thighs were compressed against each other when the dummy was leaned forward.

3. Inertia Reel Locked/Unlocked Condition - Several of the tests were conducted with the inertia reel manually locked to determine whether manual or automatic locking had any influence on dummy movement which could effect powered retraction.

## TEST INPUTS

Input parameters to the tests were as follows:

1. Seat Acceleration and Onset - The seat acceleration was programmed to be within 12-14G with an onset rate of 180 to 200 G/sec. It is normal to expect some degree of variance between similar ejections when comparing accelerations and onsets. This is primarily due to incomplete burning of the cartridge propellent in the catapult tube and other contributing factors such as changes in ambient temperature, movement of the dummy in the seat, number of tests conducted during the day, and variations in interpretation of instrumentation results.

2. PIR/Catapult Firing Sequence - To obtain reproducible and accurate timing of the inertia reel firing with respect to catapult initiation, a special electronic sensing system was developed to interact with the mechanical firing system of the catapult. This system was designed to detect the movement of the catapult head firing pin just after its release via an optical sensor. The sensor provides a signal to initiate a timing circuit which controls both strobe light actuation and inertia reel firing. The timing circuit introduces a preset time delay before directing current to an MK-17 electric initiator, which when fired produces the pressure needed to fire the PIR cartridge, which in turn provides the pressure to retract the inertia reel straps. The electronic timing circuit was set for a zero time delay between the catapult firing pin release and initiation of the MK-17 squib. However, a 20-msec. delay was noted between catapult ignition and first indication of inertia reel cartridge pressure buildup due to inherent delays in the system which could not be reduced using the setup described. During discussions with McDonnell Douglas Aircraft Corporation personnel, it was learned that this 20-msec. delay was within the tolerance of the firing circuit of the A-7 and A-10 escape systems.

## TEST RESULTS

Test conditions and results are summarized in table III. The tests were conducted in sets so that a comparison could be made between similar initial conditions, with the exception that the inertia reel would either be ballistically initiated or remain passive. Data was obtained to determine what effect powered retraction had on the dummy during the ejection power stroke.

The PIR's were shown to be ineffective in torso retraction prior to or during onset of acceleration. Once the acceleration reached a peak (approximately 4 in. of stroke and 90 msec.) the powered reel began to retract the torso. In the human analog, spinal collapse and resultant injury is considered to occur within 4 to 6 inches of ejection stroke corresponding to onset of acceleration. The spinal column is exposed to the highest injury potential during the initial onset of acceleration, making proper alignment essential during this period in order to prevent spinal injuries.

## PHOTOGRAPHIC ANALYSIS

Graphs showing the dummy's head and shoulder displacement with respect to the headrest are shown in figures 3, 4, 5, and 6. These graphs were digitized

TABLE III

TEST CONDITIONS/RESULTS

| TEST NO. | DATE | DUMMY INITIAL DISPLACEMENT (IN.) | (CM) | INERTIA REEL POWERED | INERTIA REEL LOCKED (L) UNLOCKED (U) | INERTIA REEL CARTRIDGE FIRING TIME (MSEC) | SEAT $G_z$ (G) | $G_z$ ONSET (G/SEC) | CATAPULT SEPARATION TIME (MSEC) | LEFT RISER LOAD (LB) | (NT) | RIGHT RISER LOAD (LB) | (NT) | PEAK CHEST $G_x$ (G) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8/26/77 | 5 | 12.7 | No | L | -- | 13.3 | 189 | 178 | 186 | 827 | 137 | 609 | 7.1 |
| * 2 | 8/26/77 | 5 | 12.7 | Yes | L | 21 | 13.4 | 196 | 182 | -- | -- | -- | -- | -- |
| 3 | 9/02/77 | 5 | 12.7 | No | U | -- | 12.9 | 217 | 184 | 237 | 1054 | 195 | 867 | 8.5 |
| 4 | 9/02/77 | 5 | 12.7 | Yes | U | 20 | 13.4 | 203 | 180 | 228 | 1114 | 195 | 867 | 6.1 |
| 5 | 9/07/77 | 1 | 2.5 | No | L | -- | 12.8 | 169 | 183 | 102 | 454 | 84 | 374 | 3.4 |
| 6 | 9/07/77 | 1 | 2.5 | No | L | -- | 13.6 | 182 | 183 | 96 | 427 | 80 | 355 | 3.3 |
| 7 | 9/08/77 | 1 | 2.5 | Yes | L | 23 | 14.0 | 186 | 176 | 89 | 396 | 101 | 449 | 3.4 |
| 8 | 10/20/77 | 3 | 7.6 | No | U | -- | 13.0 | 196 | 182 | 179 | 796 | 242 | 1076 | 9.4 |
| 9 | 10/20/77 | 3 | 7.6 | Yes | U | 23 | 13.0 | 157 | 186 | 132 | 587 | 200 | 890 | 7.1 |
| 10 | 10/21/77 | 3 | 7.6 | No | U | -- | 12.9 | 162 | 185 | 216 | 960 | 295 | 1312 | 10.0 |
| 11 | 10/27/77 | 3 | 7.6 | Yes | U | 19 | 13.1 | 155 | 185 | 122 | 542 | 188 | 836 | 6.5 |
| 12 | 10/28/77 | 5 | 12.7 | Yes | U | Not Recorded | 12.4 | 161 | 184 | 192 | 854 | 222 | 987 | 8.1 |

* No Test - Inertia reel strap jammed while retracting.

** Delay from release of catapult firing pin to PIR cartridge pressure indication.

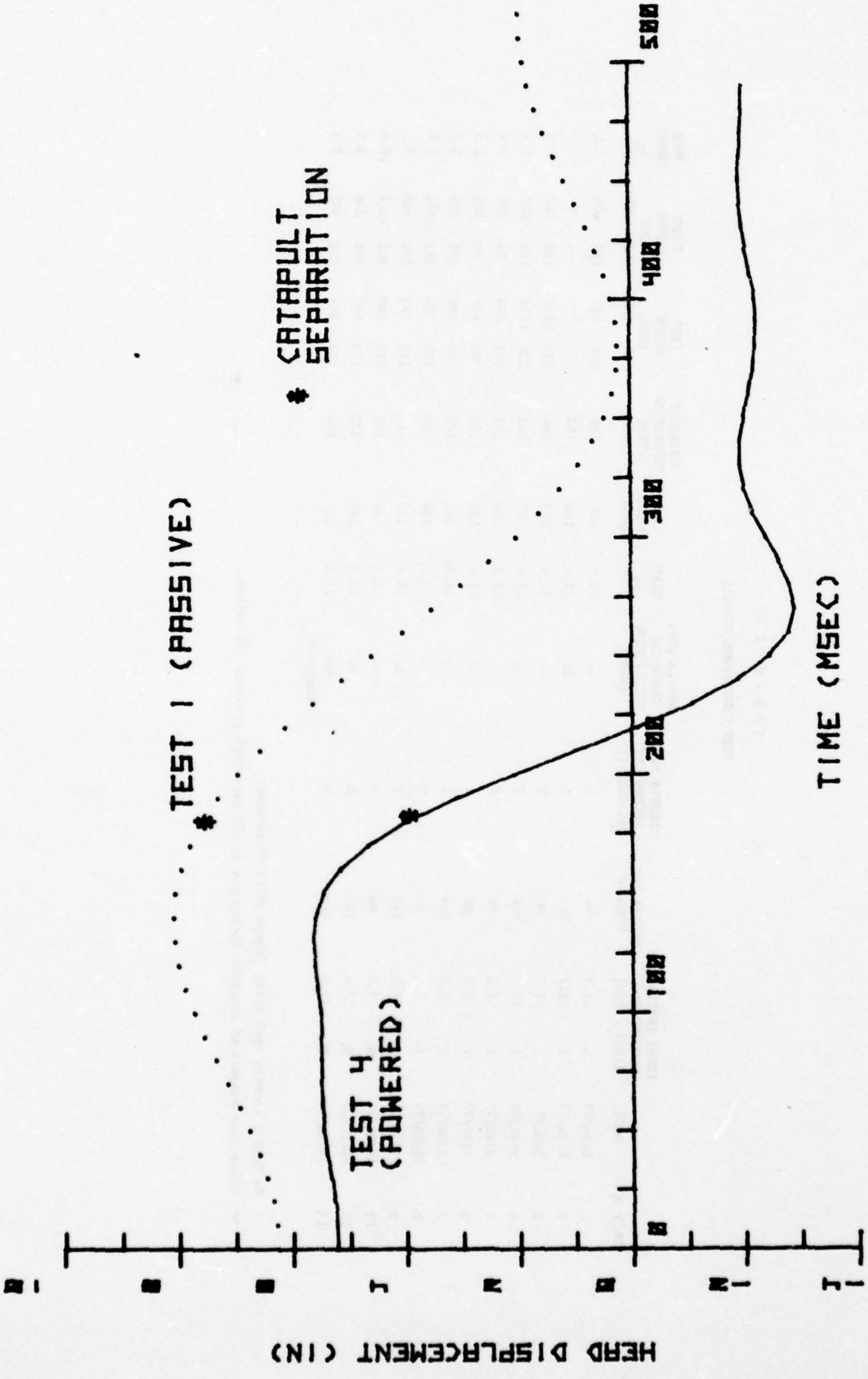



FIGURE 3 - Head Displacement - Tests 1 and 4

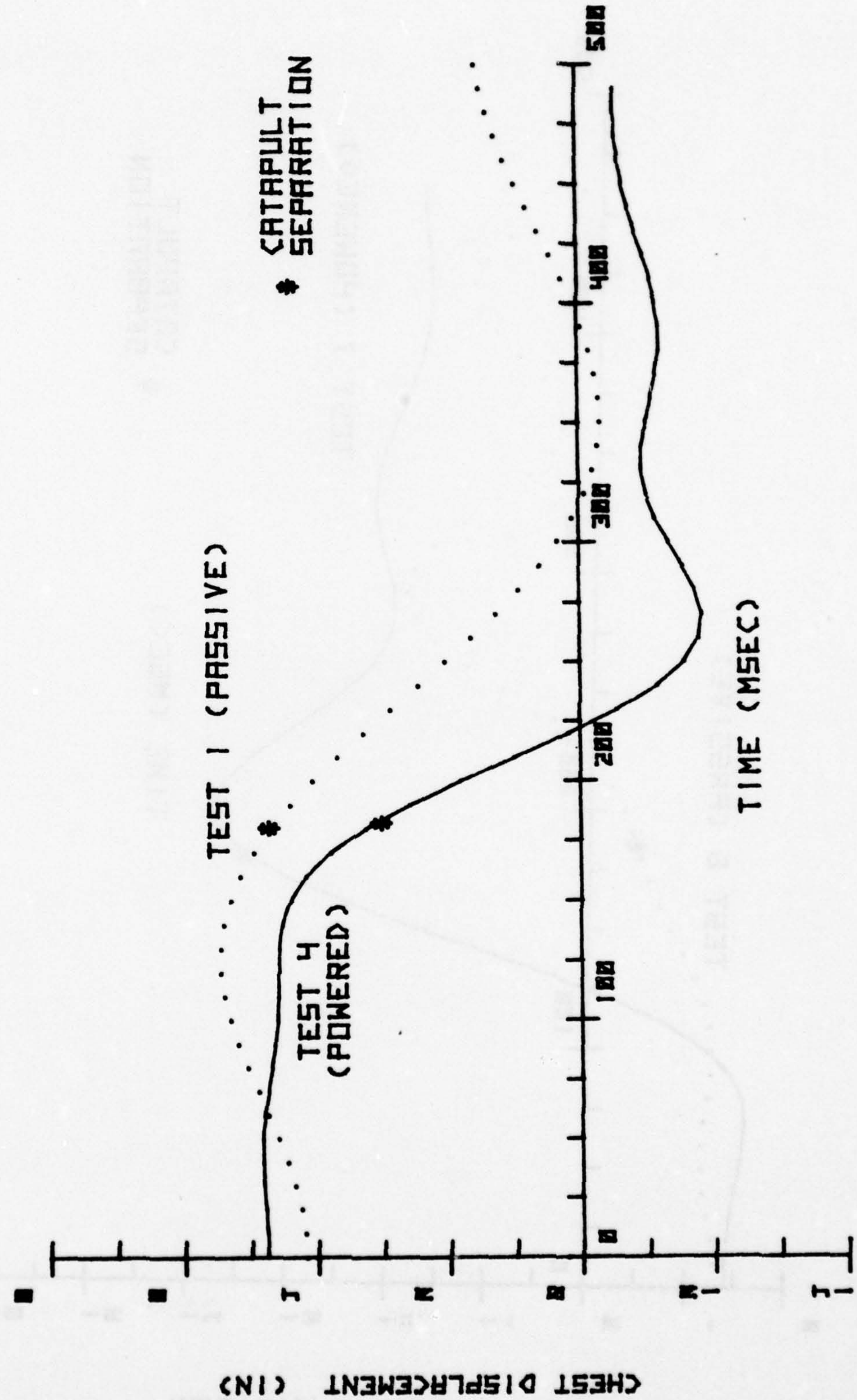



FIGURE 4 - Shoulder Displacement - Tests 1 and 4

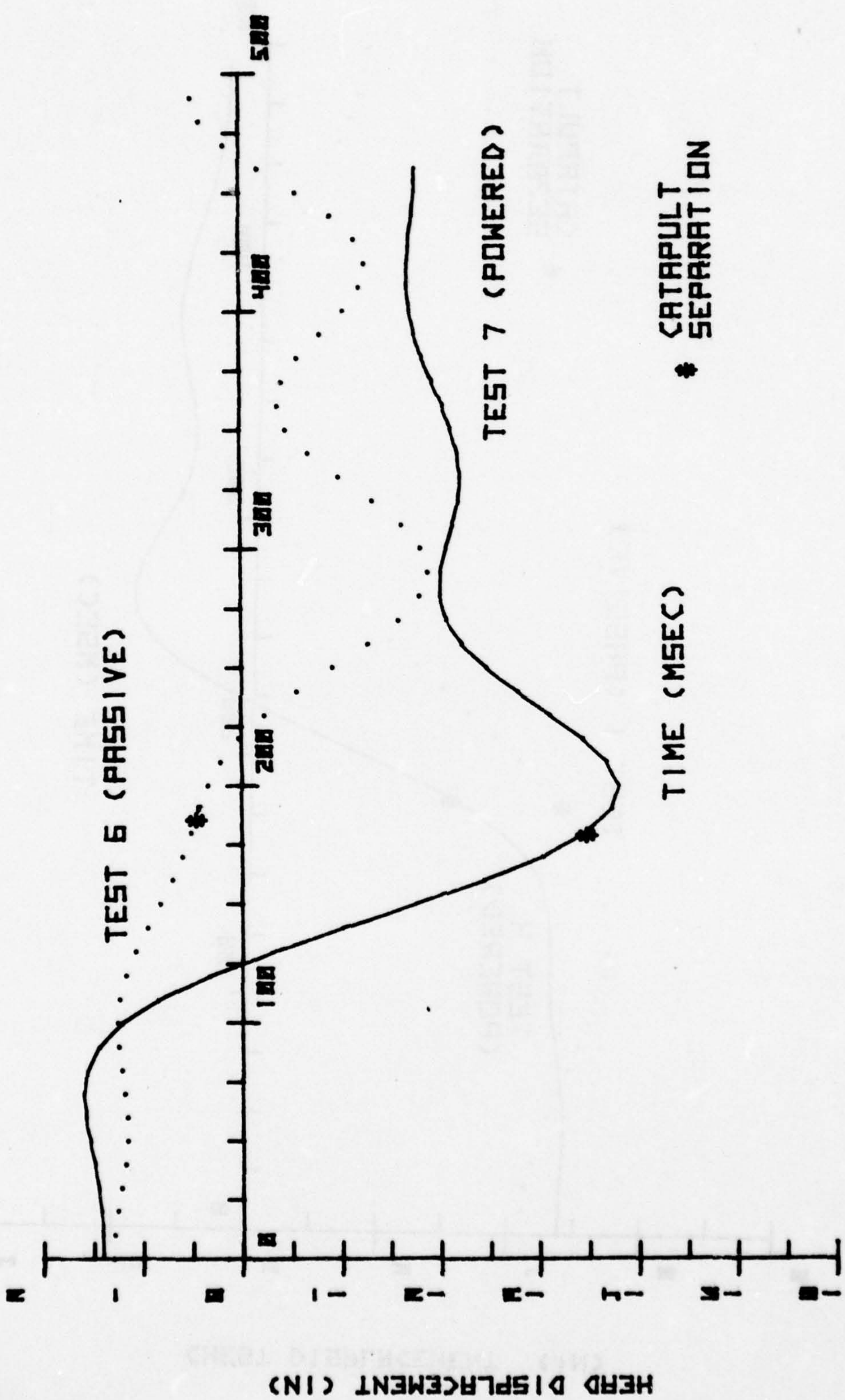



FIGURE 5 - Head Displacement - Tests 6 and 7

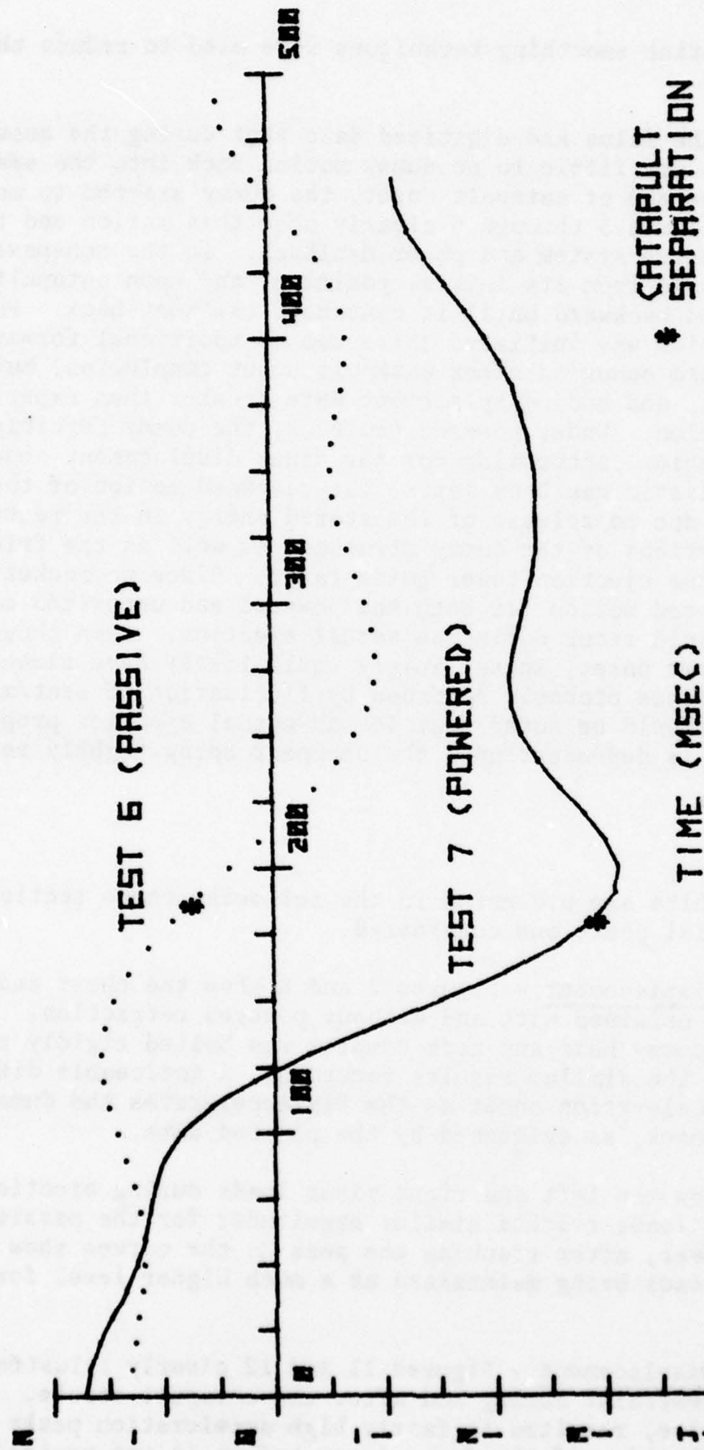



FIGURE 6 - Shoulder Displacement - Tests 6 and 7

from film records and routine smoothing techniques were used to reduce the effect of data scatter.

It is obvious from the films and digitized data that during the onset of the catapult stroke there was little to no dummy motion back into the seat. However, subsequent to the end of catapult onset, the dummy started to move toward the seat back. Figures 3 through 6 clearly show this motion and the differences between a passive system and power haulback. In the non-powered case the dummy moved forward from its initial position, and upon catapult tube separation the dummy moved backward until it contacted the seat back. For those cases where power retraction was initiated there was no additional forward motion. Dummy displacement backward occurred after catapult onset completion, but aided by power retraction, head, and body displacement were greater than experienced during the passive condition. Under powered haulback, the dummy forcibly compressed the seat back cushion, accounting for the minus displacement shown in the figures. During non-ballistic haulback tests, the rearward motion of the dummy after catapult onset was due to release of the stored energy in the restraint and compressed rubber portions of the dummy structure as well as the frictional deceleration induced by the ejection tower guide rails. Since no rocket is present in these tests, the rearward motion for both the powered and unpowered cases was not indicative of what would occur during an actual ejection. Even though the PIR becomes effective after onset, spinal injury would likely have already occurred and system performance probably degraded by fluctuation of seat/man c.g. during rocket burn. It should be noted that for an actual ejection proper rocket thrust/c.g. relationship is dependent upon the occupant being tightly restrained in the seat.

INSTRUMENTATION RESULTS

Instrumentation results are presented in the following three sections for the three different initial positions considered.

2.5 cm (1 in.) Initial Displacement - Figures 7 and 8 show the chest and head horizontal accelerations obtained with and without powered retraction. As explained previously, the dummy head and neck complex was bolted rigidly to the torso which accounts for the similar results recorded. A noticeable difference occurs after catapult acceleration onset as the PIR accelerates the dummy more rapidly toward the seat back, as evidenced by the plotted data.

Figures 9 and 10 show the left and right riser loads during ejection. During catapult stroking, strap loads reached similar magnitudes for the passive or powered condition. However, after reaching the peak G, the curves show distinct differences with strap loads being maintained at a much higher level for the powered retraction test.

7.6 cm (3 in.) Initial Displacement - Figures 11 and 12 clearly illustrate how the PIR affects the dummy restraint during and after the catapult stroke. Tests 8 and 10 which were passive, resulted in fairly high acceleration peaks caused by the forward velocity buildup of the dummy torso before it was restrained by the shoulder straps. After peak acceleration was attained, there was rebounding of the torso toward the seat back and a deceleration as it contacted structure. In comparison, tests 9 and 11, which were powered retractions, showed accelera-

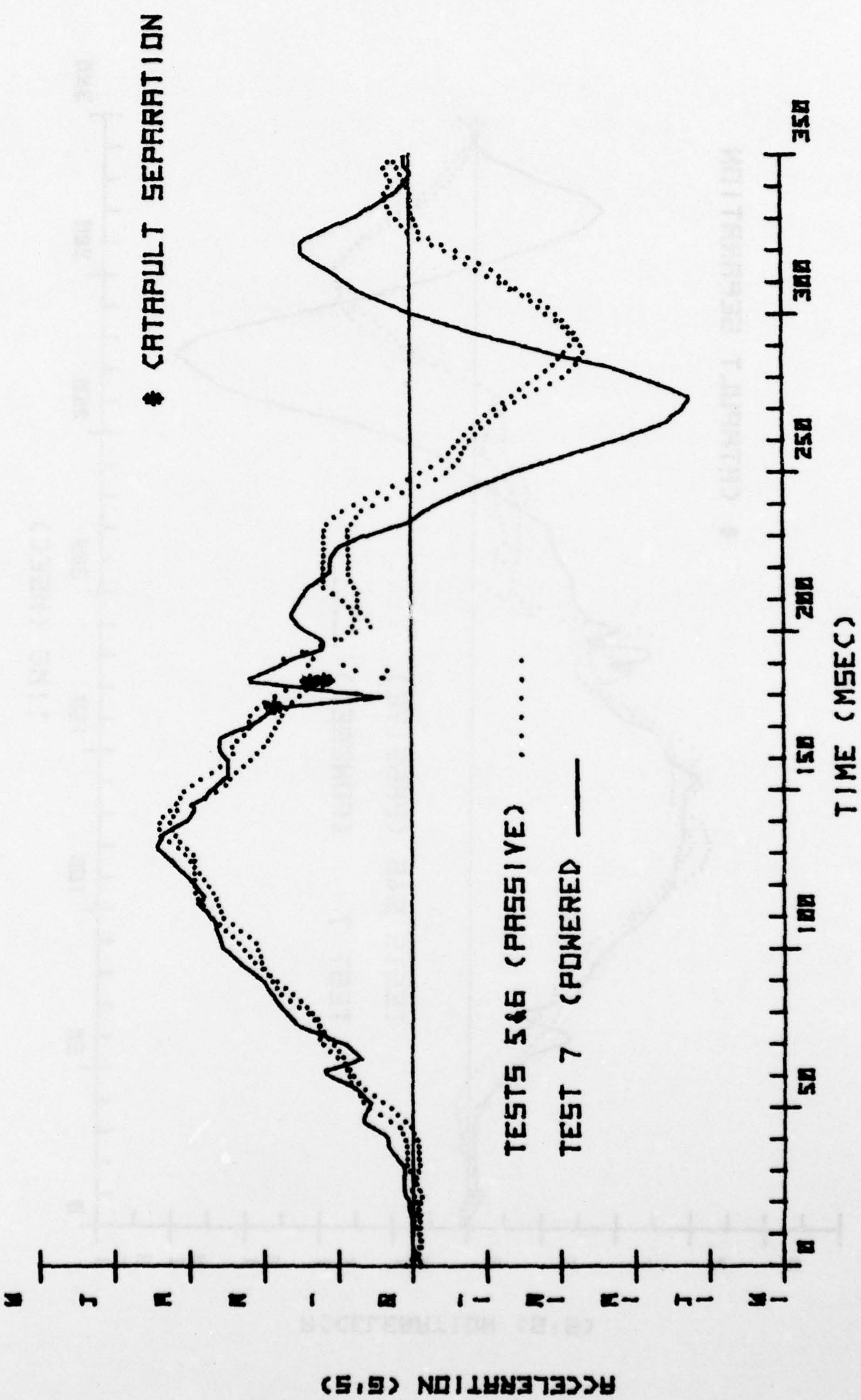



FIGURE 7 - Chest Acceleration - Tests 5, 6, and 7

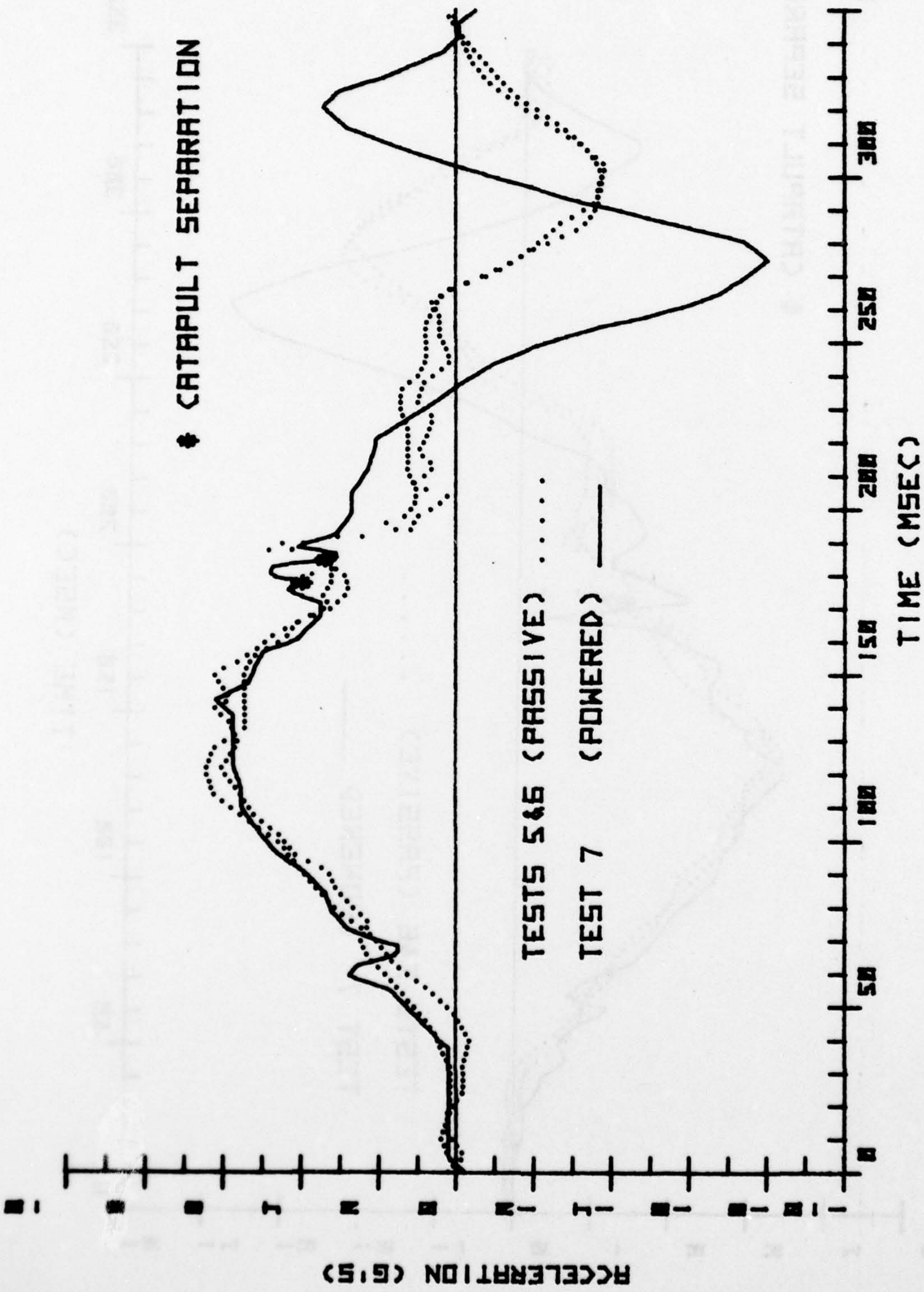



FIGURE 8 - Head Acceleration - Tests 5, 6, and 7

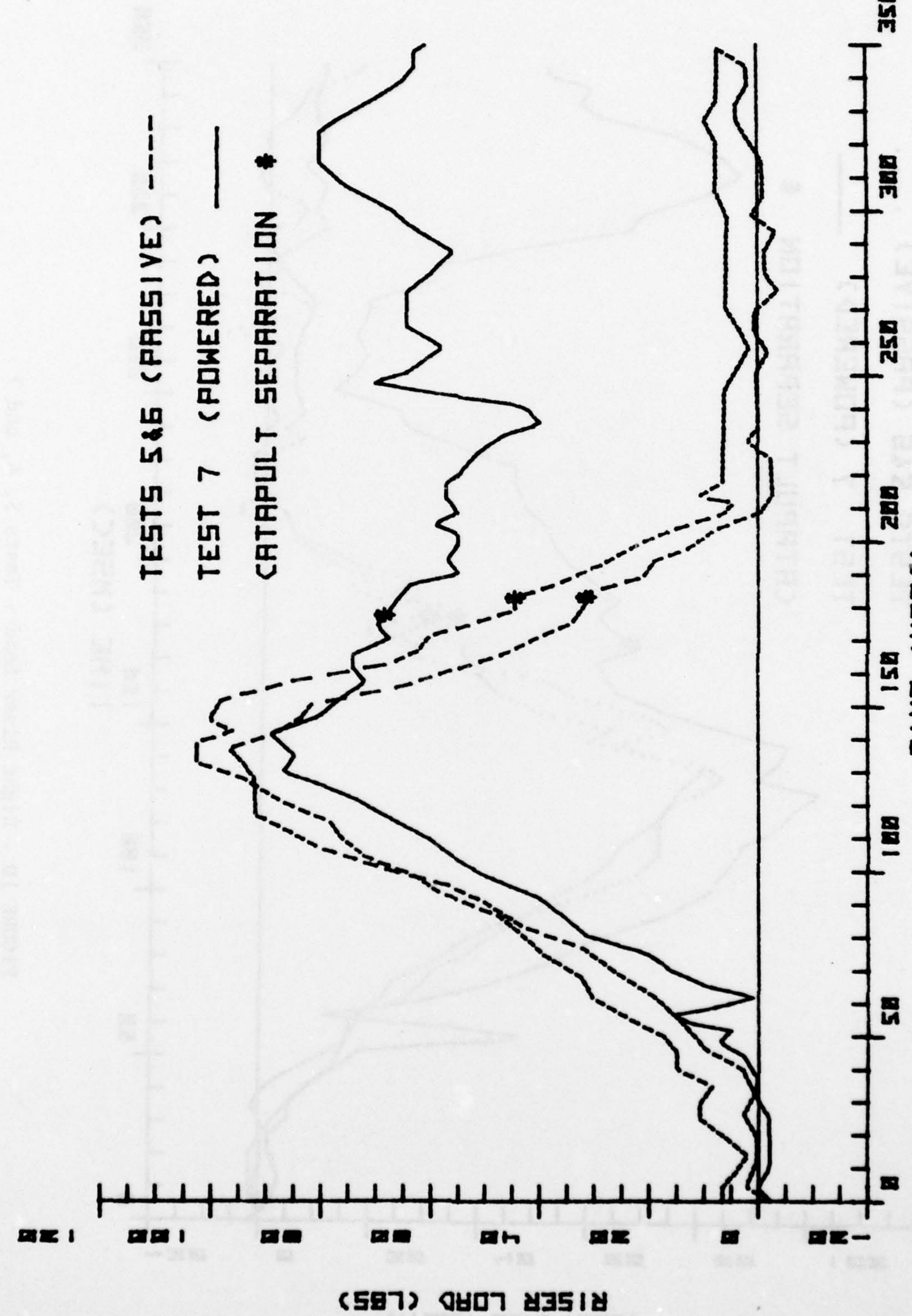



FIGURE 9 - Left Riser Load - Tests 5, 6, and 7

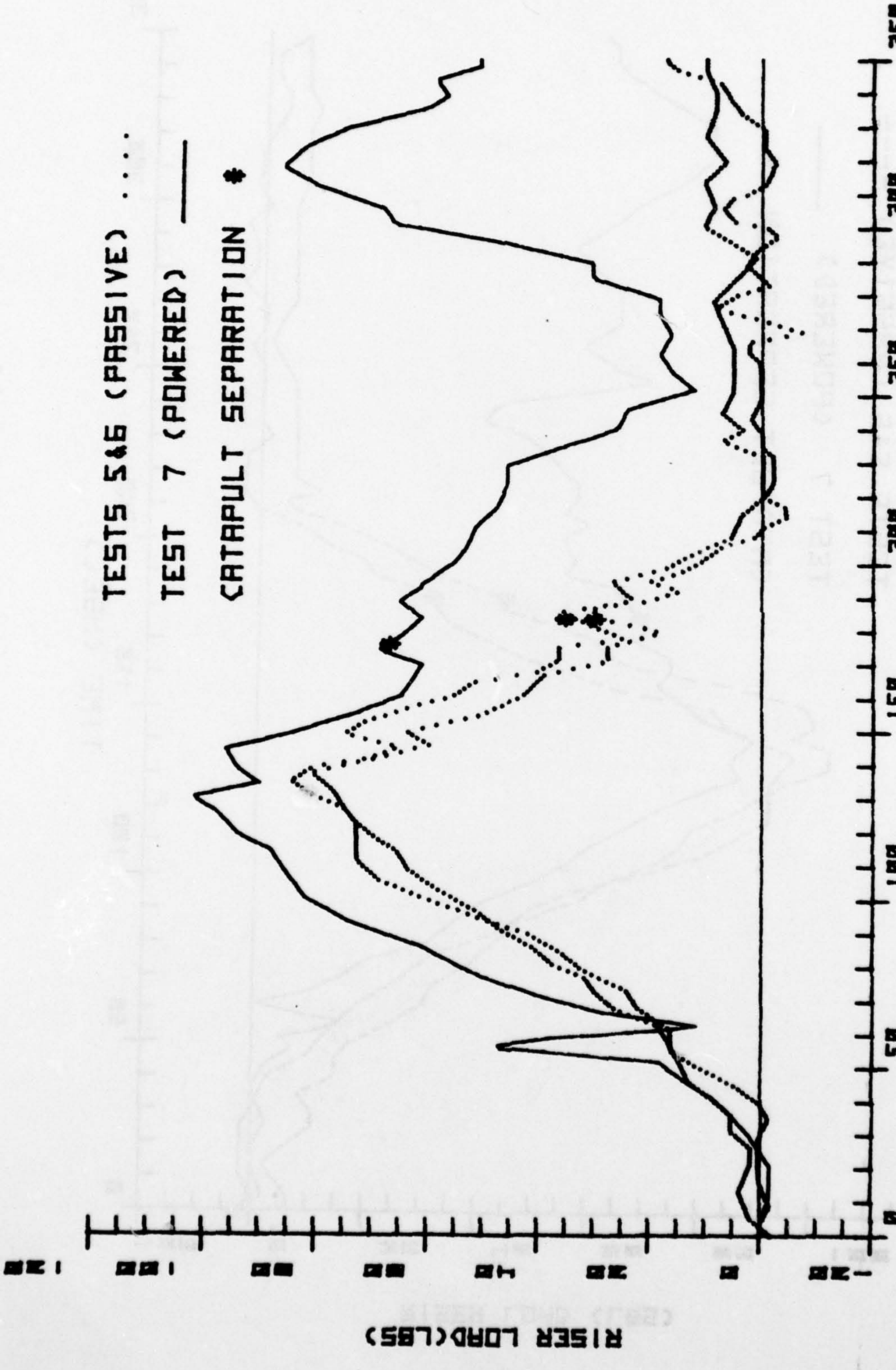



FIGURE 10 - Right Riser Load - Tests 5, 6, and 7

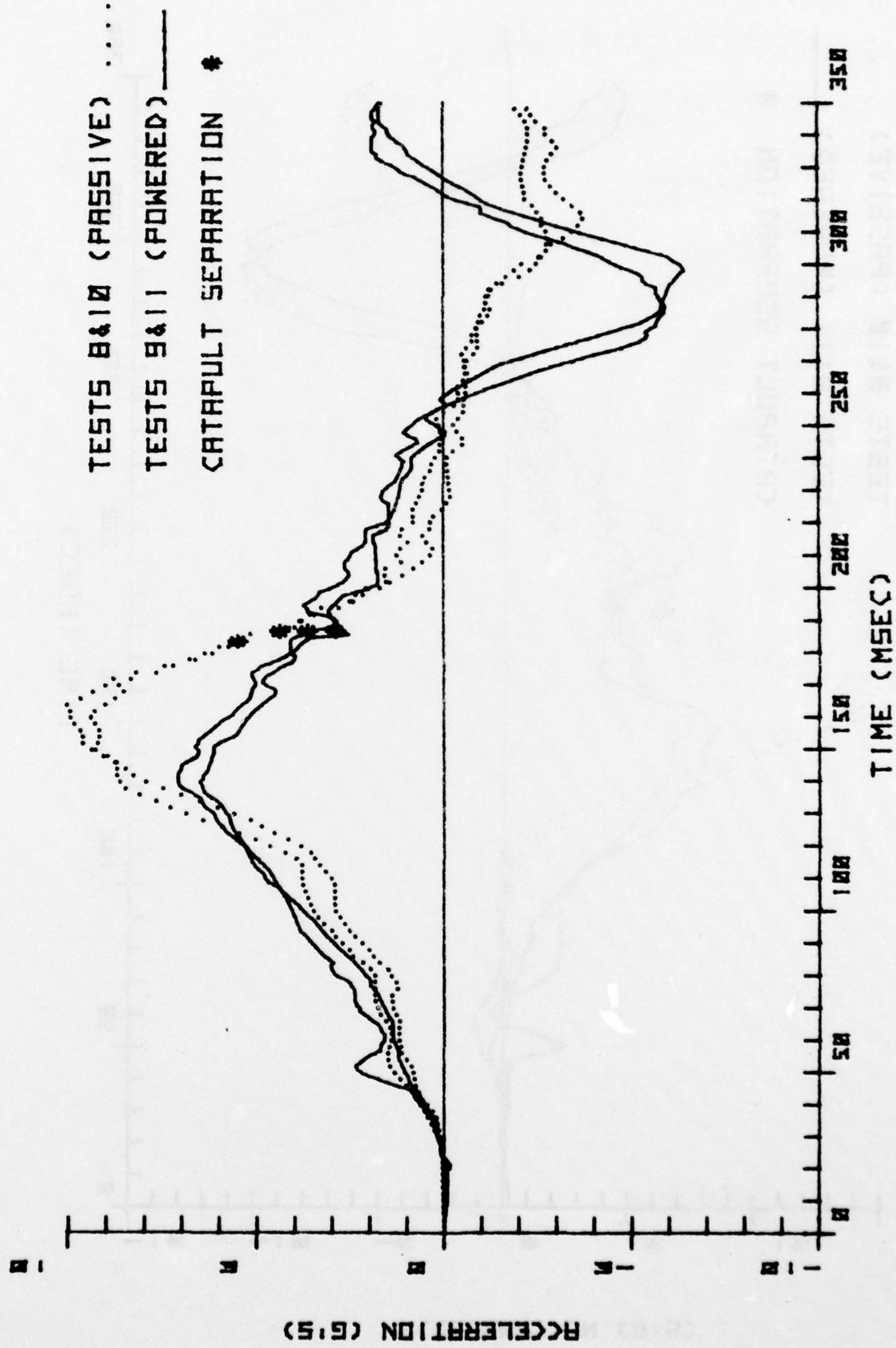



FIGURE 11 - Chest Acceleration - Tests 8, 9, 10, and 11

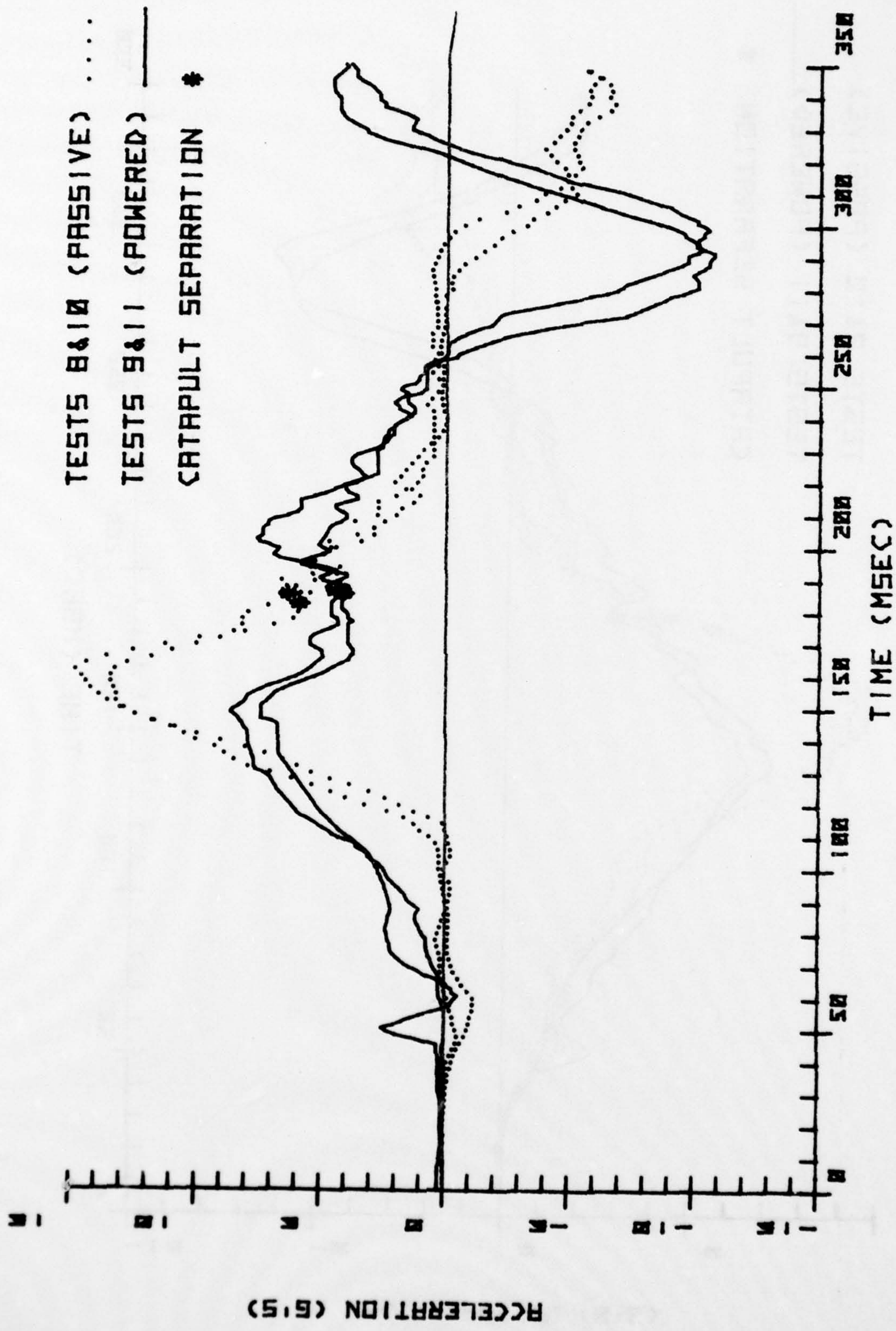



FIGURE 12 - Head Acceleration - Tests 8, 9, 10, and 11

tion to occur with a more rapid rise time and achievement of lesser peaks than the passive tests. The reason for this difference lies in the action of the PIR which took up shoulder strap slack and therefore coupled the restraint to the torso sooner in the ejection sequence, although it did not generate sufficient power to move the torso backward during the major portion of the catapult stroke. After this delay, the inertia reel forces induced an acceleration on the torso as it moved back toward the seat and subsequently contacted the seat structure. Figures 13 and 14 show the accompanying loads for the accelerations described above showing the PIR's application of load on the risers to differ from the passive tests.

12.7 cm (5 in.) Initial Displacement - Figures 15, 16, 17, and 18 show results similar to the previously described tests. It should be noted that as the dummy was initially positioned further forward from the seat back, it coupled more effectively with the shoulder straps and therefore influenced the shape of the curve. Additionally, the horizontal accelerometers mounted within the dummy cavity measured a larger vertical component of acceleration.

Inertia Reel Cartridge Pressure - Cartridge pressure measured during powered retraction varied considerably, as can be seen from the plots in figure 19. It is characteristic of the cartridge pressure to vary according to the amount of strap extension from the reel since this has an effect on the initial internal volume of the powered section of the reel. However, the curves show an apparent inconsistency since similar conditions did not produce similar results. In an attempt to determine whether the pressure transducer used to monitor cartridge pressure had any influence on the performance of the PIR, it was removed for Test No. 12. There was no apparent change in the performance of the PIR with the transducer removed. From conversations with Pacific Scientific Corporation engineers, these inconsistencies in pressure for similar conditions can be expected without degradation of system performance.

Inertia Reel Locked/Unlocked Results - The PIR was tested in either a locked (manual) or unlocked (automatic) condition to determine whether this initial setting would have any effect on the test outcome. In its unlocked mode it automatically locked as designed when strap motion exceeded the velocity necessary to actuate lockup. Test data indicated that the powered take up was unaffected by its initial lock/unlock position.

## ACKNOWLEDGEMENTS

The authors wish to extend their appreciation to those personnel from the Aircraft and Crew Systems Technology Directorate and the Technical Services Department who participated in this program and contributed to this report.

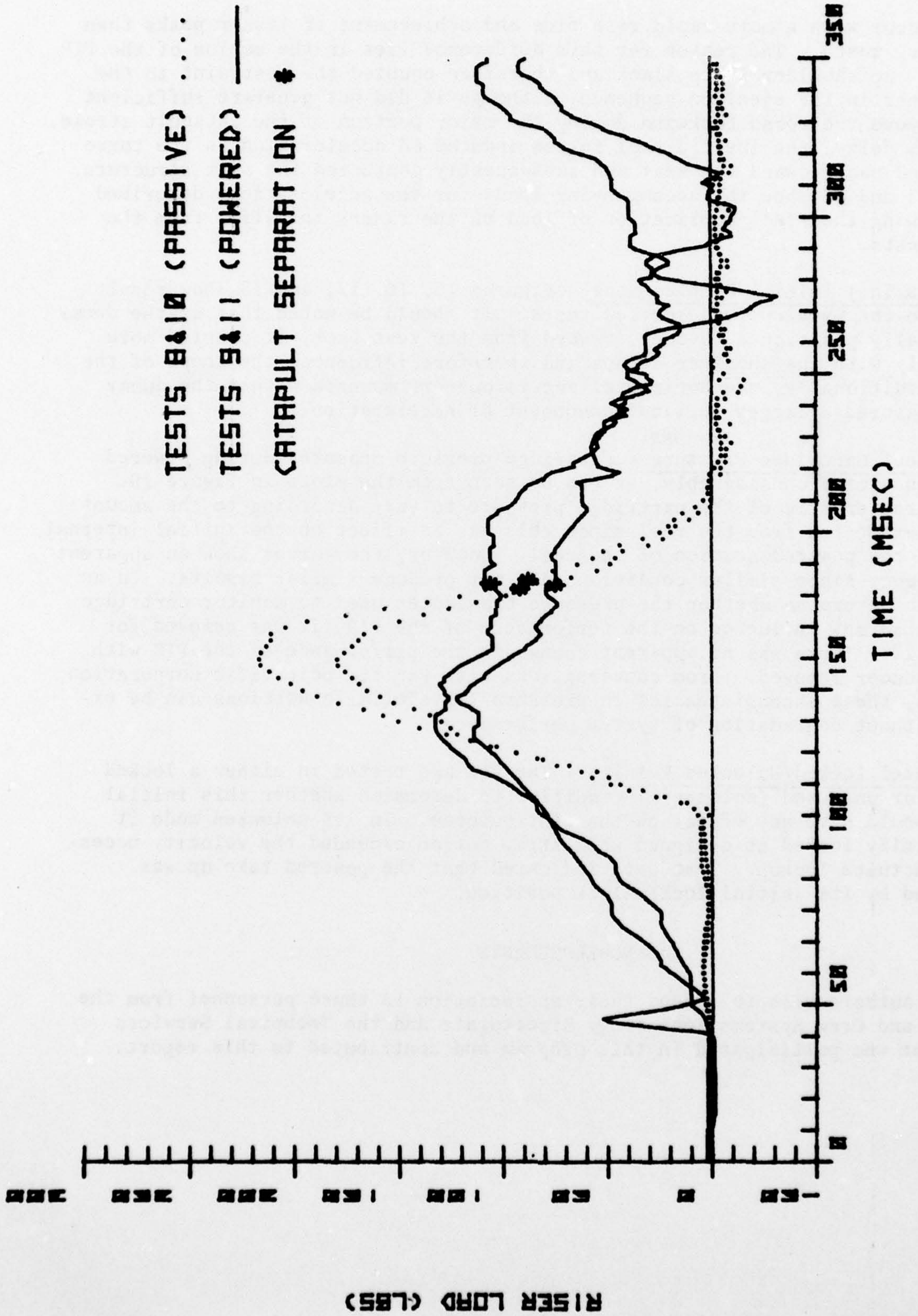



FIGURE 13 - Left Riser Load - Tests 8, 9, 10, and 11

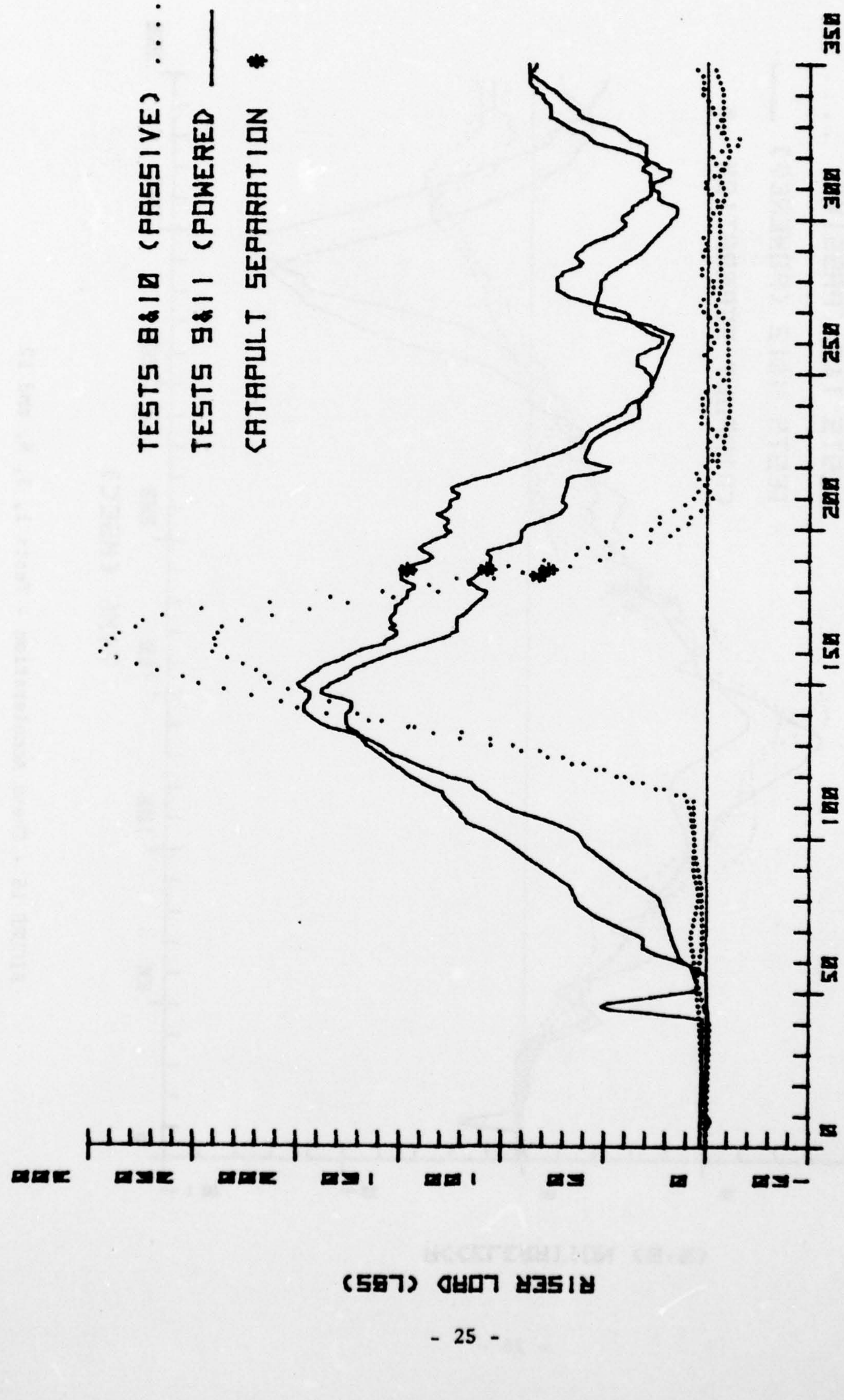



FIGURE 14 - Right Riser Load - Tests 8, 9, 10, and 11

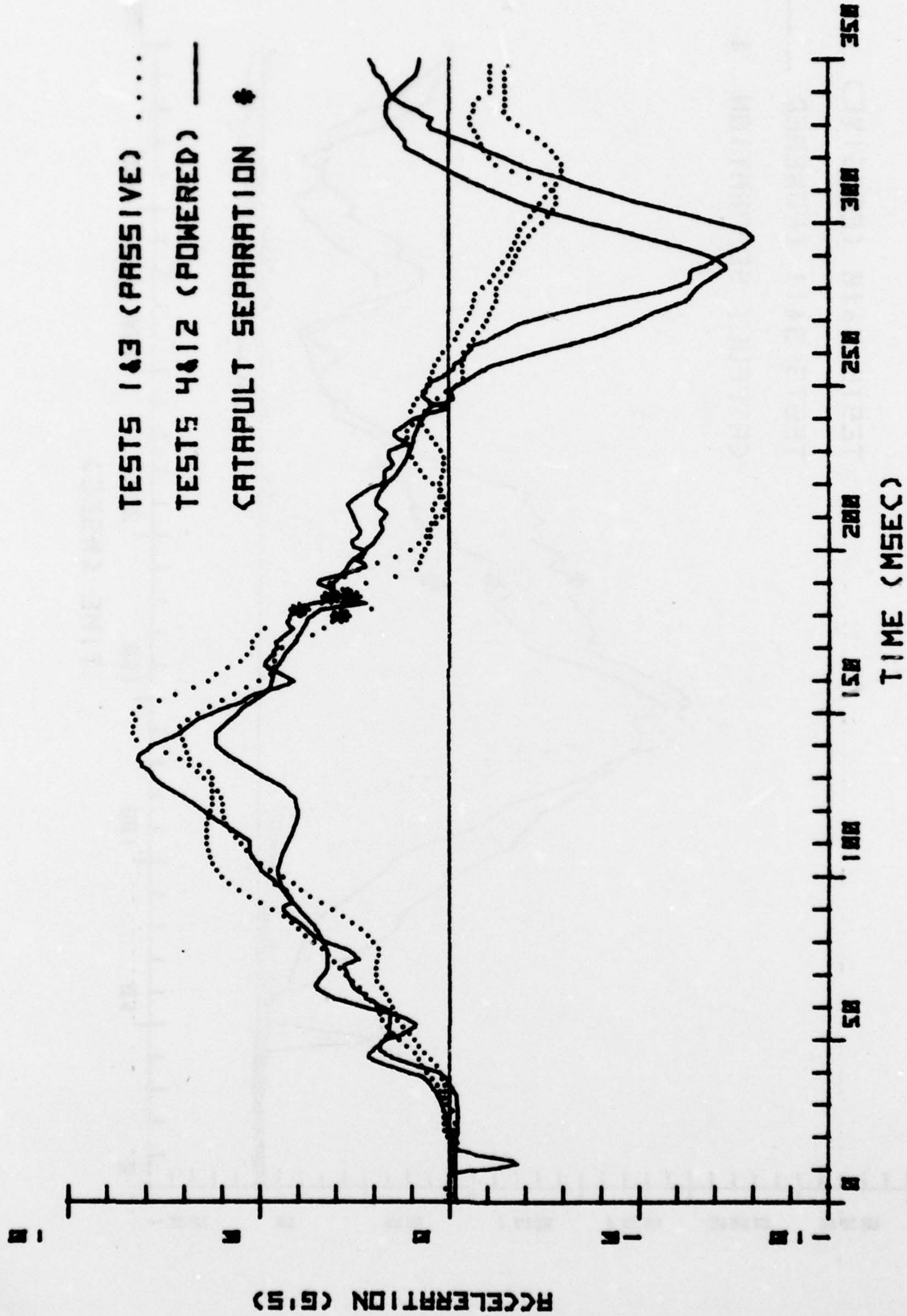



FIGURE 15 - Chest Acceleration - Tests 1, 3, 4, and 12

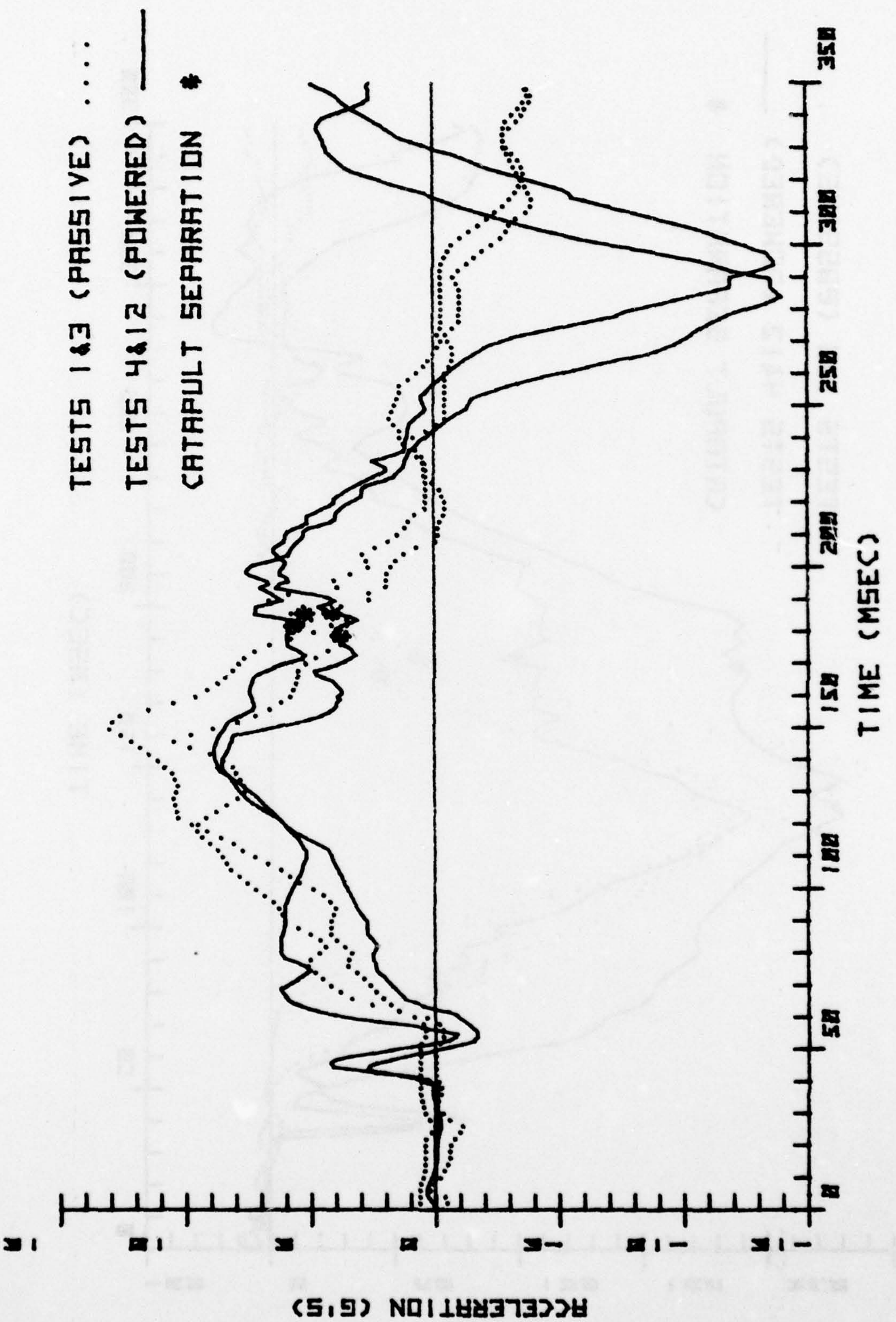



FIGURE 16 - Head Acceleration - Tests 1, 3, 4, and 12

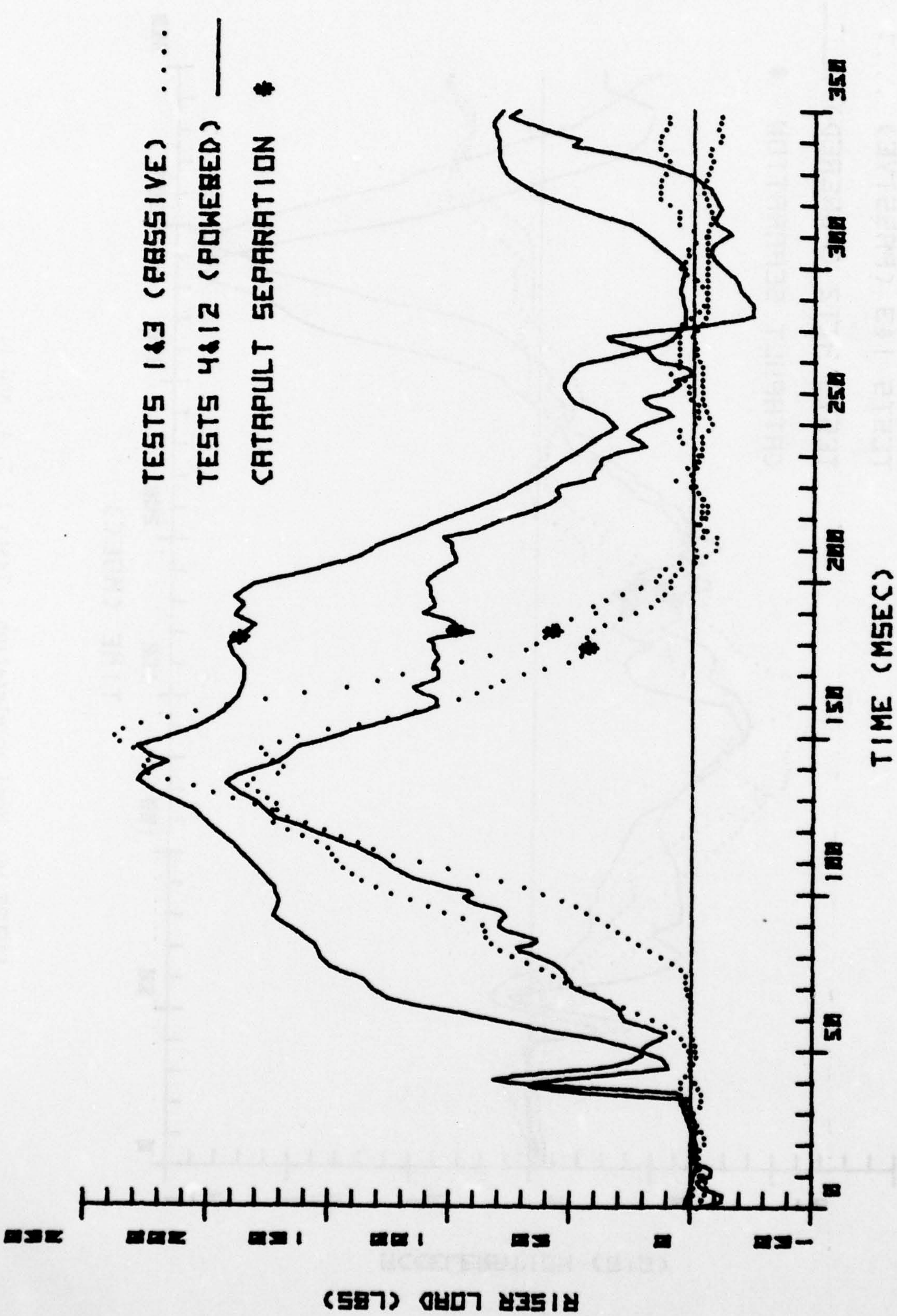



FIGURE 17 - Left Riser Load - Tests 1, 3, 4, and 12

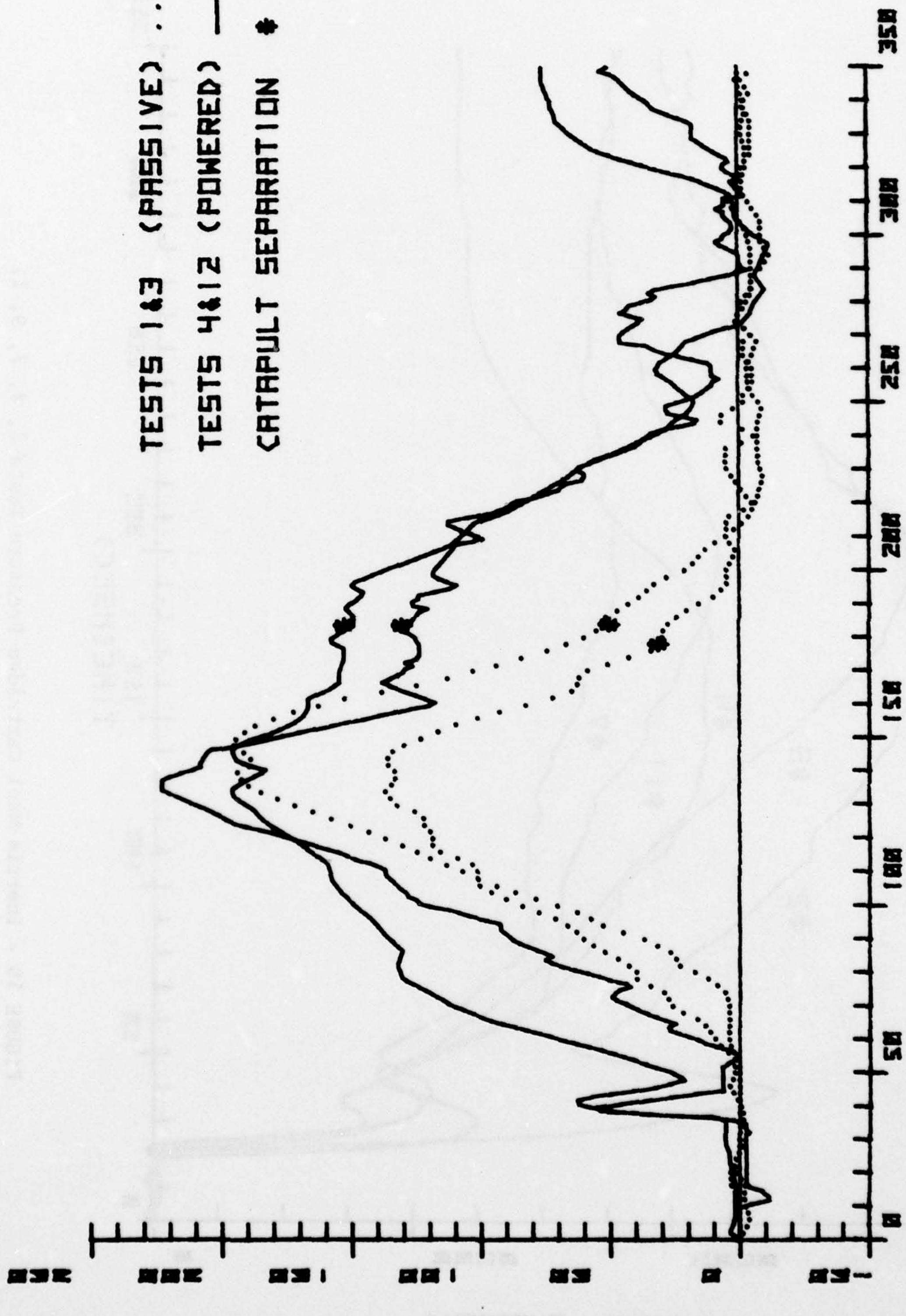



FIGURE 18 - Right Riser Load - Tests 1, 3, 4, and 12

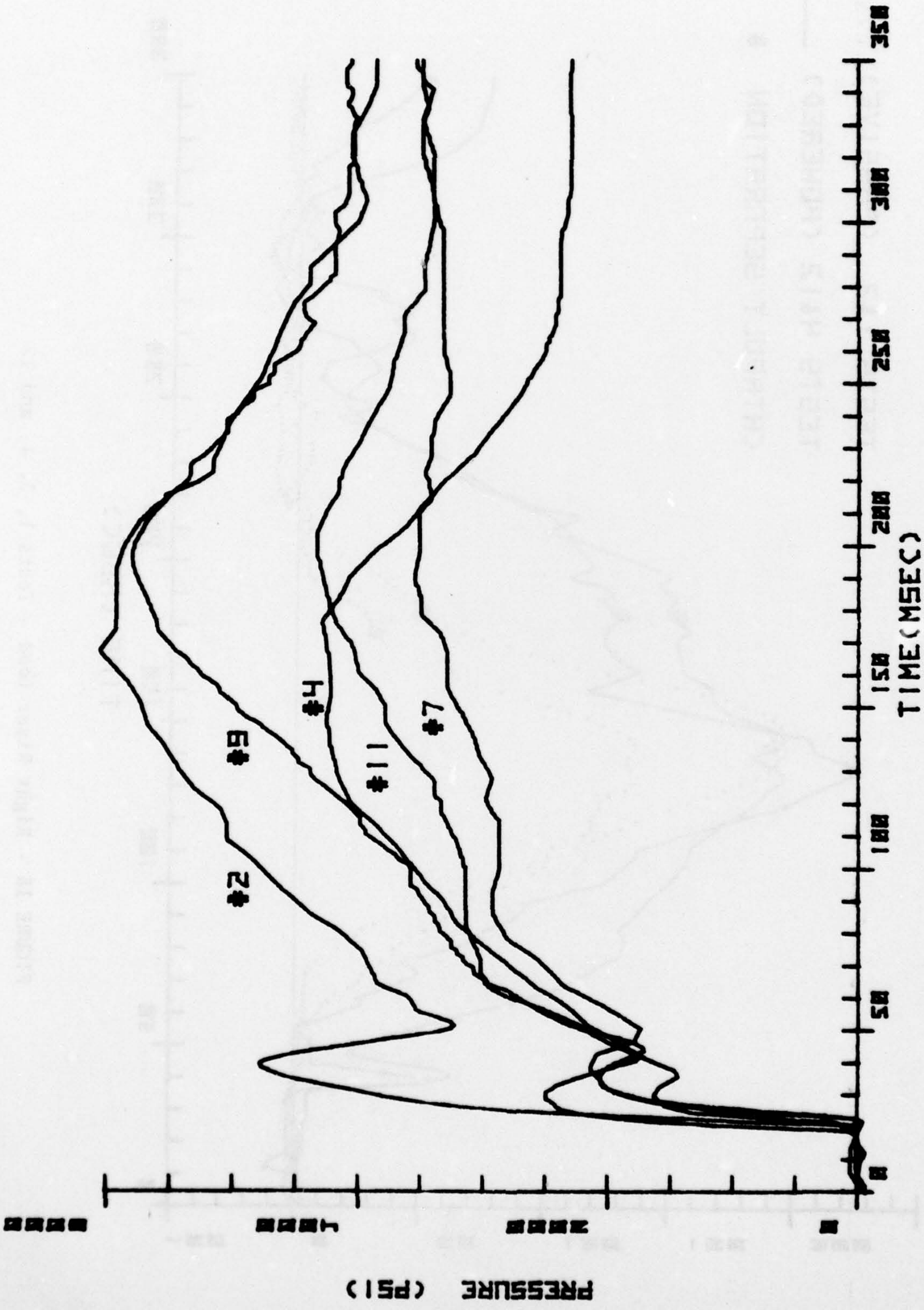



FIGURE 19 - Inertia Reel Cartridge Pressure Tests 2, 4, 7, 9, 11